Design characterization and automatic identification of character lines in automotive field

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Abstract

In the automotive domain a great importance is given to the design style and the designer is expected to create shapes that originate emotional states in the potential user. In this context the designer's position is twofold being a technician and an artist at the same time. This role is fundamental for the performance of a new product launched into the marketplace.
The methodology proposed in this paper aims at defining a design support tool for the definition of shapes in the automotive sector. This methodology is based on the study of the most relevant character lines.
These lines are automatically selected by means of CAD tools and then analyzed identifying mathematical relations between such lines and other geometrical features typical of the car. This part of the methodology originates a mathematical definition of the style that is associated to a qualitative definition of the style based on data coming from user surveys analyzed through statistical tools.
Based on the two definitions above mentioned, a methodology to connect geometrical and emotional data has been developed. This methodology has been applied to a set of cars showing the results presented in the paper.
Cars' appearances and the emotional feelings they produce are linked together; some relationships are deduced, to create a support tool in the early design phase.

1 Introduction

In the automotive domain a great importance is given to the design style and the designer is expected to create shapes that originate emotional states in the potential user. In this context the designer's position is twofold being a technician and an artist at the same time. This role is fundamental for the performance of a new product launched into the marketplace. The design process strikes a balance between engineering, market and style choices.
Although the aesthetics concept has been widely discussed in philosophy since the 18th century, recent literature attempts to examine the relationships between shape and aesthetics in the industrial production.
Starting from the early Nineties, researchers focused on the correlation between product appearance and the associated emotional states. In civil engineering the effort done in developing design methods to make bridges and dams aesthetically appealing is reported in ([1], [2], [3], [4]). In the industrial design field, Claessen ([5]) investigates the interaction between colour and shape of industrial products; Kurango ([6]) develops a tool to obtain 3D digital models derived from conceptual sketches. Further investigations concern IT tools for product development aiming at automatically converting the design intent and concepts into detailed design taking into account the production technologies and the user perception ([7], [8], [9]).
Van Breemen ([10]) deepen the link between shape and appearance identifying some physical relations between aesthetical functions and the geometrical parameters that define a shape. On this background, a theory about the design intent communication through product shape is elaborated identifying a formal mapping between the shape features space and the aesthetical features space ([11]).
In 2000, an EU funded project named FIORES-II (Character Preservation and Modelling in Aesthetic and Engineering Design) was launched with the aim of extending Reverse Engineering methods to aesthetical and emotional design. The tools developed within FIORES II may release designers from mathematical and topological constraints in shape design enabling them to focus on their style concepts ([12]).
More recently, in [13], a research about the use of character lines in car design has been performed developing a code that enables to automatically identify the main character lines in a car through an image processing analysis.
In this framework, the methodology proposed in this paper aims at defining a design support tool for the definition of shapes in the automotive sector. This methodology is based on the study of the most relevant character lines. These lines are automatically selected by means of CAD tools and then analyzed identifying mathematical relations between such lines and other geometrical features typical of the car. This part of the methodology originates a mathematical definition of the style that is associated to a qualitative definition of the style based on data coming from user interviews analyzed through statistical tools.
Based on the two definitions above mentioned, a methodology to connect geometrical and emotional data has been developed.
This methodology has been applied to a set of cars showing the results presented in Section 3.

2 Methods and tools

The methodology proposed in this paper is based on:

- an analytical study of the car character lines that aims at a mathematical definition of the style of a car;
- an analysis of the emotional states originated by the style of a car in order to qualitatively define them.

Some CAD (Computer Aided Design) tools are adopted to analyze the shape of the car together with some specific scripts developed in Matlab. In the qualitative definition of the style, a survey is performed by means of individual questionnaires and statistical analysis tools.

2.1 Mathematical definition of the style

The first step in the character lines identification is the definition of a database of car profiles. As known, in point to point modelling the so-called blueprints are widely used as a basis for the object modelling. The reference pictures are generally orthogonal projections in the following directions: top, bottom, front, rear, right, left. They are obtained as copy of detailed drawings of the product and their name comes from the USA custom of copying them in negative so that they appear as white drawings on a blue background (Fig. 1). Differently in Europe they are copied in positive from the original drawing so that they appear in blue/black drawings on a white background (Fig. 2).

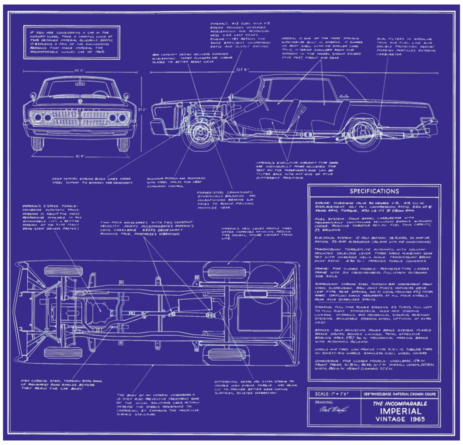


Fig.1 Blue print: example of representation with American standard

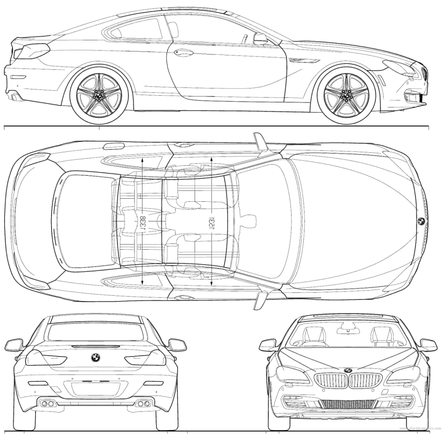


Fig.2 Blue print: example of representation with European standard

The collection of blueprints has been followed by an image processing phase to identify the character lines. The image processing is a particular type of signal analysis in which the input consists in an image, a picture or a movie while the output is a new image or a set of features or parameters representing the original input as, for example, the character lines of a car.

In this case the limited number of car models considered does not deserve the use of automatic image processing algorithm. Therefore a manual procedure has been adopted. It is based on the use of Rhinoceros, a CAD software that enables to modify, analyze, render, animate and translate both curves and surfaces, based on the parametric representation of curves and surfaces.

The left view of each blueprint is extracted and loaded in the Rhinoceros working environment as a background bitmap (Fig. 3). In this phase the image size and resolution are scaled in order to make the parameters of different cars comparable. The reference dimension used for the normalization is the interaxis distance of the car represented by the blueprint. Once loaded the blueprint left view, the following curves are selected using the command "Interpolated curves" (Fig. 4):

- the roof line;
- the waist (or belt) line (the curve dividing the side windows and the body side);
- the wheelbase line;
- the accent line(s) (if any, one or more curves just below the waist line).

In addition to the curves listed above, the circles representing wheels/pneumatics and its centres are extracted from the blueprint together with some relevant parameters such as: the distance between wheelbase line and waist line d_1, the distance between the waist line and the roof line d_2 and their ratio r_{12} (Fig. 5).

The roof camber is estimated with simpler geometrical entities such as circle arches and line segments; for each car a maximum number of two circle arches has been considered to fit the roof camber. The diameter of the circle(s) Di_1 and Di_2 together with the horizontal distance between the circles' centres D_C are considered.

In the case of sports car the parameter $d_3 = d_1 + d_2$ and the ratio between the diameter of the circle Di_1 and d_3 are considered (D_d).

Further parameters are considered such as the windshield tilt angle α and the back window tilt angle β by means of the parameters $p_1 = \sin\alpha$ and $p_2 = \sin\beta$.

Moreover, the typical technical data such as: car length l, car height a and the interaxis distance i are combined together to calculate the following parameters.

$$C_a = \frac{l}{a} \tag{1}$$

$$C_{ai} = \frac{C_a}{\sqrt{\frac{i}{100}}} = \frac{10l}{a\sqrt{i}} \tag{2}$$

It is to notice that most part of the parameters considered are dimensionless as obtained through the ratio between lengths.

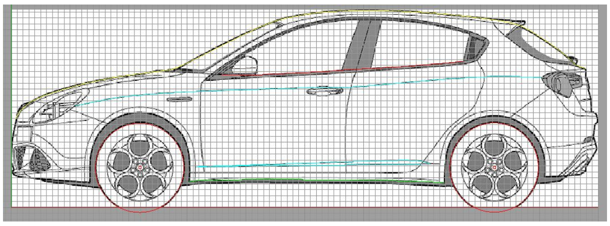


Fig.3 Identification of character lines using Rhinoceros software

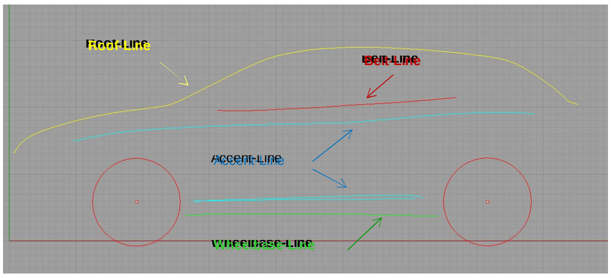


Fig.4 Selection of the main character lines

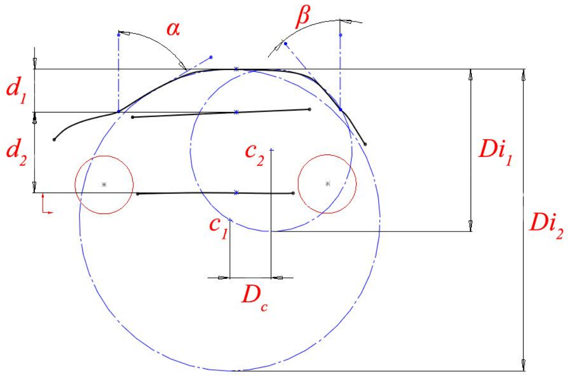


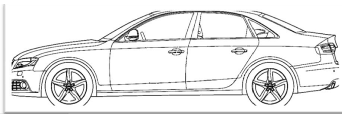
Fig.5 Car design parameters

2.2 Qualitative definition of the style

Each car is characterized by some distinguishing traits that define its design. Curves, edges and lines are elaborated by the human brain wreaking emotions perceived by the user. This is one of the designer's goal.
The analysis of such emotions is quite a difficult task. In this study it has been approached through a test aiming at deriving the emotional features originated by a specific car design.
The survey is conducted on a small sample consisting in twelve volunteers which are asked to allocate at least three words, selected among a list of twenty-one adjectives, to each car analysed in the survey (Fig. 6).
The car design is intentionally presented by means of the grey-scale lateral view of the car in order to better emphasize the character lines without affecting the judgment.
Once collected the data, these are ranked in order to classify the preferences for each car.
Data are analysed and presented by means of bar graphs in which preferences for each car model are represented in a percent scale.
The adjectives that present a percentage higher than 50% are selected and associated to the car model (Fig. 7).

Which of the following adjectives better describes the vehicle?

(Please select at least three words)



1	Aggressive	2	Angular	3	Directional
4	Dynamic	5	Fat	6	Feminine
7	Geometric	8	Sharp-edges	9	Low
10	Masculine	11	Modern	12	Old-fashioned
13	Sensual	14	High	15	Slender
16	Skinny	17	Soft	18	Stable
19	Powerful	20	Elegant	21	Static

Fig. 6 Example of the survey questionnaire

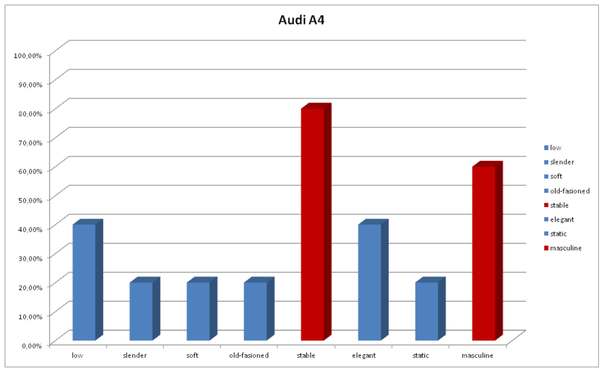


Fig. 7 Example of the survey results

3 Results and discussions

The described analysis of character lines is performed on different car models, belonging to different market sectors, with the aim to define relations between emotional feelings and geometrical shapes.

3.1 Experimental set up

Fifteen car models have been selected, coming from almost all cars typologies. The choice is influenced by aesthetical criteria, car notoriety and reputation, its brand importance and its role in the marketplace. By these considerations, all market segments are taken into account and for each of them some car models have been selected.
Between cars which belong to C-Segment, Alfa Romeo Giulietta and Volkswagen Golf are selected. The first one is the restyling of an old car and it is a new model, while VW Golf is an evergreen of this car segment. Chrysler Voyager is selected to represent the high level Minivan division. Moreover, Chrysler PT Cruiser is analyzed thanks to its unconformable aesthetical lines.
Sedan cars are one of the most notable cars for each brand: Audi A4, BMW 5 Series and Mercedes-Benz E-Class are some of the most known top level cars of this segment. New Fiat 500 is a *city-car*, particularly appreciated by young people for its aesthetical appearance and design features.
Sport utility vehicle (SUV) segment is a large growth sector: in this context BMW X3 and AUDI Q5 are chosen. Jeep Wrangler is selected as a jeep design.
Finally, some sports car are selected and analyzed. A lot of different car models and brands belong to this car segment and the choice was performed with the aim to define cars which could represent at best the whole sports cars domain. Ferrari 599, Pagani Zonda, Dodge Viper and BMW Z4 are chosen.

3.2 Results

The fifteen selected cars are analyzed in Rhinoceros, in order to identify their character lines. Obtained files are imported in a parametric CAD environment to measure identified parameters on those curves and to define sketch dimensions (Fig. 8).

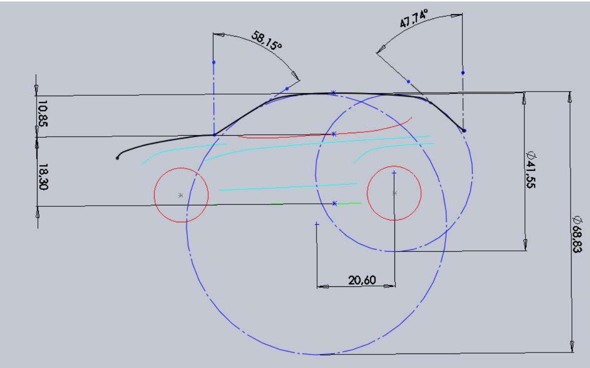


Fig. 8 Sketch for geometry measurements

Some geometrical data are also obtained from technical data sheet provided by manufacturers. All input data are collected in a *Microsoft Excel sheet* to obtain the whole representation of data and coefficients, in order to find some notable relationships. The following tables resume this data collection and analysis procedure (Tab. 1, Tab. 2 and Tab. 3).

Car Model	l	a	i	C_a	C_{ai}
Alfa Romeo Giulietta	4351	1465	2634	2.970	0.5787
Audi A4	4701	1427	2808	3.294	0.6217
Audi Q5	4629	1653	2807	2.800	0.5286
BMW 5 Series	4899	1464	2968	3.346	0.6142
BMW Z4	4239	1291	2496	3.283	0.6572
BMW X3	4648	1675	2810	2.775	0.5235
Chrysler PT Cruiser	4288	1601	2616	2.678	0.5236
Chrysler Voyager	408	1503	2878	3.199	0.5963
Dodge Viper	4460	1230	2510	3.626	0.7238
Ferrari 599	4665	1336	2750	3.492	0.6658
Fiat 500	3566	1488	2300	2.396	0.4997
Jeep Wrangler	4223	1865	2373	2.264	0.4648
Mercedes E Class	4868	1471	2878	3.309	0.6169
Volkswagen Golf VI	4199	1479	2578	2.839	0.5592
Pagani Zonda	4886	1141	2785	4.282	0.8114

Tab.1 Design parameters in relation with selected car model

Car Model	P_1	P_2	r_{12}	D_c	D_d
Alfa Romeo Giulietta	0.9066	0.7754	1.955	18.64	2.055
Audi A4	0.8930	0.9139	1.838	9.97	
Audi Q5	0.8390	0.6388	1.741	20.2	
BMW 5 Series	0.8744	0.9222	2.018	11.31	
BMW Z4	0.8999	0.8658	1.804		2.577
BMW X3	0.8492	0.7398	1.687	20.6	
Chrysler PT Cruiser	0.8460	0.5736	1.741	28.23	
Chrysler Voyager	0.8748	0.6998	1.605	28.23	
Dodge Viper	0.8860	0.9707	1.792		2.290
Ferrari 599	0.8910	0.9610	2.106		2
Fiat 500	0.8625	0.6426	1.870	8.45	
Jeep Wrangler	0.5348	0.1717	1.849		
Mercedes E Class	0.8927	0.9313	2.033	10.82	
Volkswagen Golf VI	0.8790	0.6537	1.600	19.47	
Pagani Zonda	0.9330	0.9727	1.634		1.399

Tab.2 Design parameters in relation with selected car model

Car Model	n°_c	Di_1	Di_2	d_1	d_2	d_3
Alfa Romeo Giulietta	1	51.4		16.56	8.47	16.56
Audi A4	1	75.48		15.62	8.5	15.62
Audi Q5	2	60.14	31.98	17.01	9.77	48.99
BMW 5 Series	1	56.72		16.47	8.16	16.47
BMW Z4	1	58.03		14.49	8.03	14.49
BMW X3	2	68.83	41.55	18.3	10.85	59.85
Chrysler PT Cruiser	2	67.33	34.34	17.08	9.81	51.42
Chrysler Voyager	2	52.07	39.37	16.95	10.56	56.32
Dodge Viper	1	51.03		14.3	7.98	14.3
Ferrari 599	1	47.84		16.22	7.7	16.22
Fiat 500	2	61.23	32.98	16.34	8.74	49.32
Jeep Wrangler				18.84	10.19	18.84
Mercedes E Class	1	60.58		16.77	8.25	16.77
Volkswagen Golf VI	2	62.7	34.21	15.46	9.66	49.67
Pagani Zonda	1	29.33		13.01	7.96	13.01

Tab.3 Design parameters in relation with selected car model

Data obtained by statistical tools are crossed with car design parameters, so that unvocal relationships between car induced emotional states and its geometries are obtained.

3.3 Discussions

Information obtained with the data crossing procedure is related to cars belonging to the same car segment.
Sports cars are associated to the following adjectives:

- BMW Z4: low, aggressive, skinny;
- Dodge Viper: low, aggressive;
- Ferrari 599 GTB: low, aggressive, sensual, dynamic;
- Pagani Zonda: low, aggressive, directional, sharp edges.

The first datum considers cars height: sports cars are low. The idea to drive in proximity to the ground, find correspondences with the a parameter that is low for all sport cars. Moreover, it is to consider that the height value is measured considering the highest point on the roof line: since the roofs of those cars have a very large curvature radius, a low vertical extension is perceived.
Sports car are associated to an aggressive character: this emotional feeling is provided by some geometrical parameters. Those cars have Cai similar values (which relate a with l and i). Moreover, Ferrari, Dodge and Pagani have high back window inclination value (see p_2 values in Tab.2). Another sport car feature is typical of the roof line, that is defined by means of only one circumference, since they have a low d_2 value and a high p_2.
The second group considers sedan cars:

- BMW 5 Series: elegant;
- Mercedes-Benz E-Class: elegant, low, slender;
- Audi A4: Stable, masculine.

Since the first two cars are considered luxury cars, their design is focused on elegance: this aspect is related to

the shapes with a relationship among a, l, i such that Cai values are about 0.61. Another parameter which provides information on elegance is r_{12} value; in this case it is about 2.02 – 2.03.
SUV – jeep is the third considered group:

- BMW X3: powerful, masculine;
- Audi Q5: powerful, high, masculine;
- Jeep Wrangler: powerful, high, masculine, geometric.

Those cars are particularly high: they are perceived high also thanks to the wheel track line, which is quite high.
Jeep has a different design typology: car shape is extremely squared, so that the whole car is approximated by two rectangles. Moreover, surfaces have high inclination values. All these features make Wrangler silhouette more geometrical and masculine.
Finally, C-segment car, minivan and city-car are examined:

- Alfa Romeo Giulietta: sensual, dynamic;
- Volkswagen Golf VI: stable, masculine;
- Fiat 500: feminine, old-fashioned, sharp-edges;
- Chrysler PT Cruiser: sharp-edges, old-fashioned;
- Chrysler Voyager: fat, high.

The dynamic feature of Alfa Romeo Giulietta is derived by the roof line, the accent line and the belt line curvatures, which gives a movement-like feeling.
Both Fiat 500 and Chrysler PT Cruiser procures an old-fashioned effect. This is due to the whole geometries which remember an old car model.
Fiat 500 roof line is approximated by two circles that are close to each other and the first one has a high radius value. Finally the back window is rather sloping. These features have a sharp-edge effect. The feminine attribute is supposed to be noted due more to marketing reasons that to geometrical ones.
PT Cruiser is defined with sharp-edges adjective: this is due to the roof line that is not interrupted after the back window, but it continues, with a high curvature level, till the back part of the car. Moreover its dimensions fit its minivan role: it is high and long. The roof is described by two circles whose centre are very distant.

4 Conclusion

The described analysis aims at contributing to the development of innovative design tools for the study of style elements and their perception in the emotional sphere. A new methodology for the selection and analysis of those particular design traits defined as character lines has been developed and applied on a set of fifteen car models belonging to three different market sectors. As far as the qualitative description is concerned, a survey has been conducted involving twelve volunteers and analyzing their judgements by means of statistical tools.
A methodology to connect geometrical and emotional data has been developed and applied to the presented case study enabling to classify the analyzed car models into different style categories.
It is demonstrated that the car models belonging to the same category are characterized by similar values of the relevant parameters both in the qualitative description and in the quantitative one.
Further developments on this study are targeted to fill the gap between the designer world – typically characterized by manual tools and creative processes – and the industrial engineering world – quickly moving towards more automated design tools – in order to get these two domains closer with the positive consequence of a potential synergy between the creative process and the engineering development.

Appendix

In this section a few bar graphs and tables representing collected data are showed as examples.

- Example 1: Dodge Viper analysis

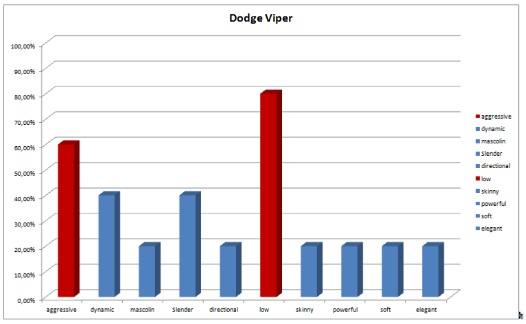


Fig. A1: results of the survey on Dodge Viper

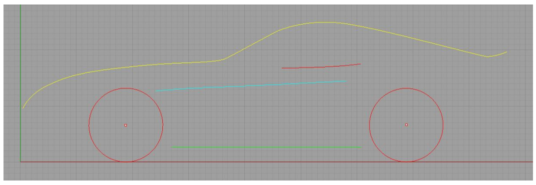


Fig. A2: Identification of character lines on Dodge Viper

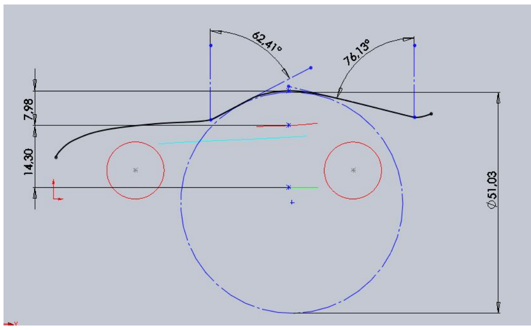


Fig. A3: Sketch for parameters measurement on Dodge Viper

- Example 2: Audi A4 analysis

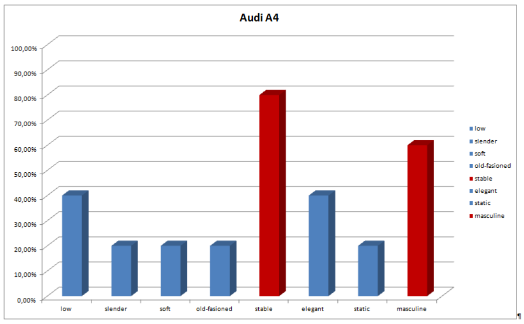


Fig. A4: results of the survey on Audi A4

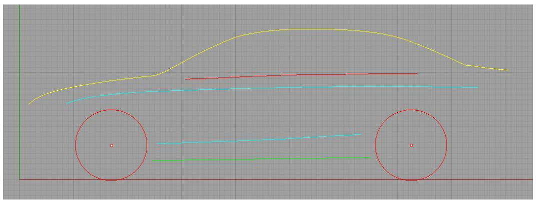


Fig. A5: Identification of character lines on Audi A4

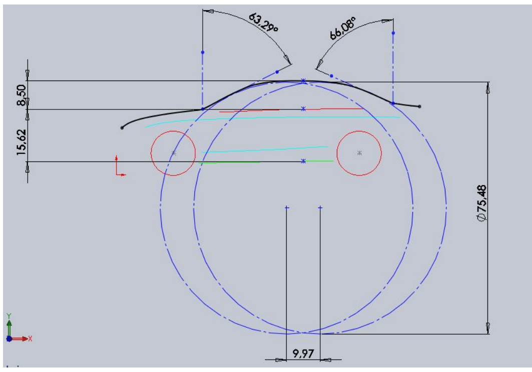


Fig. A6: Sketch for parameters measurement on Audi A4

- Example 3: Audi Q5 analysis

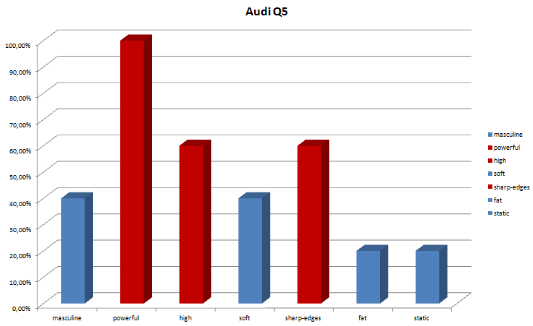


Fig. A7: results of the survey on Audi Q5

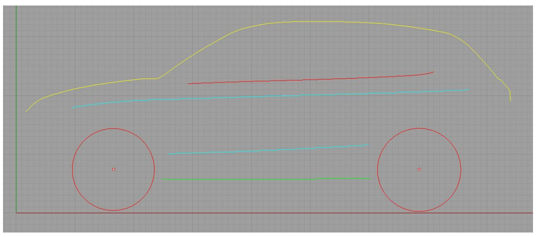


Fig. A8: Identification of character lines on Audi Q5

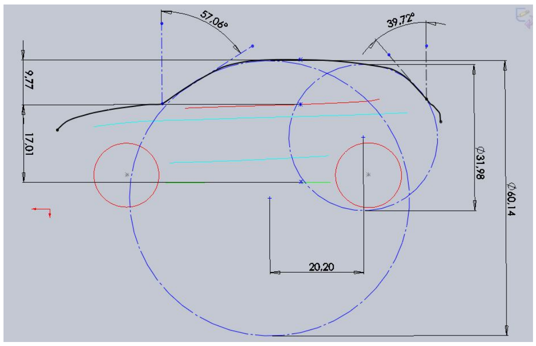


Fig. A9: Sketch for parameters measurement on Audi Q5

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